RECENT DEVELOPMENTS IN THE NIST AC-DC DIFFERENCE CALIBRATION SERVICE FOR THERMAL TRANSFER STANDARDS

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Outline

- **Brief introduction to thermal transfer standards**
  - What they are
  - Why we use them
- **The NIST Ac-dc Difference calibration service**
  - Parameter space
  - Uncertainties
- **Research activities**
  - Cryogenic thermal transfer standard
  - Film multijunction thermal converters
  - BIVD high voltage system

Introduction

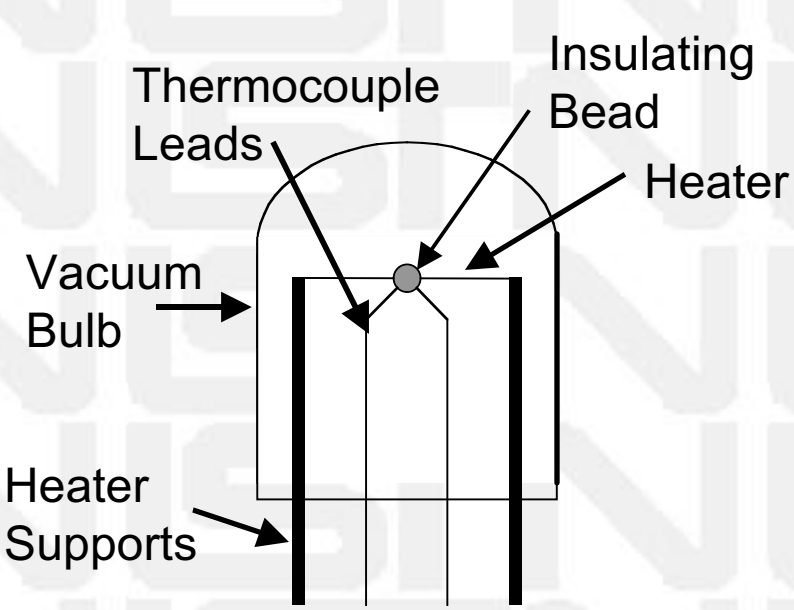
- **Customers:**
  - U.S. National Laboratories
  - Department of Defense Laboratories
  - Commercial Laboratories
- **50 to 75 Instruments per year ($125k)**
- **Active research programs**
  - CTTS to develop new primary standard
  - FMJTC to develop new working standards and high-current converters
  - BIVD system to improve high-voltage measurements

Introduction

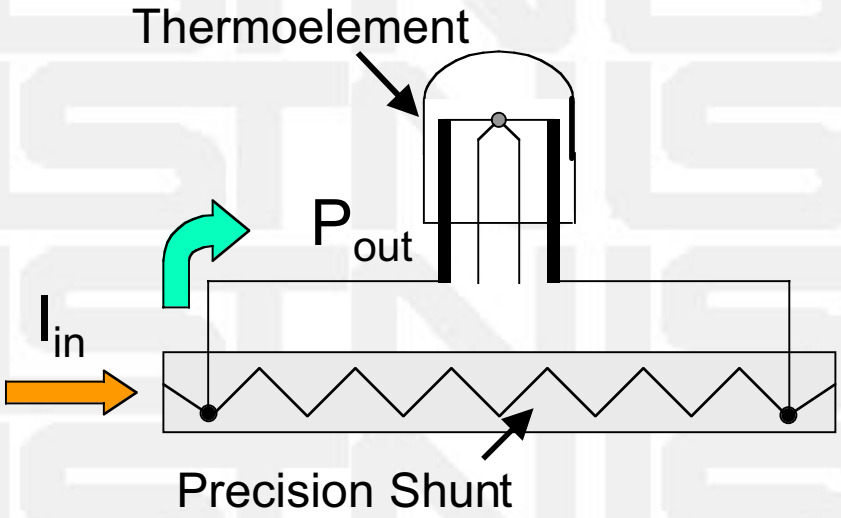
- **Thermal converters form the primary standards for calibration of**
  - Ac voltage
  - Ac current
  - Power
- **Electrothermal instruments**
  - RMS responding (direct measurement of power)
  - Simple structures - readily modeled
  - No mechanical effects to account for

Introduction

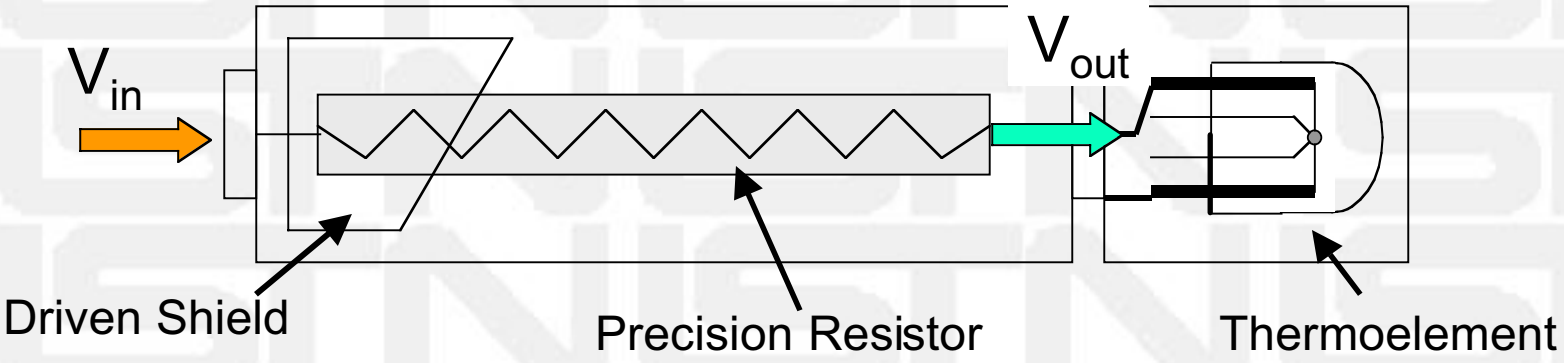
- **Basic thermoelement**
  - Rating: 1 mA - 10 mA,1 V - 4 V
  - Major error sources are thermoelectric effects and low-frequency tracking of the input signal
  - Used for both voltage and current measurements
- **Voltage Measurements**
  - Use series resistors to reduce input voltage
  - Major error sources are reactance and dielectric loss
- **Current Measurements**
  - Often use current shunts with thermoelements
  - Major error sources are current definition effects



Basic Thermoelement



Current Measurements

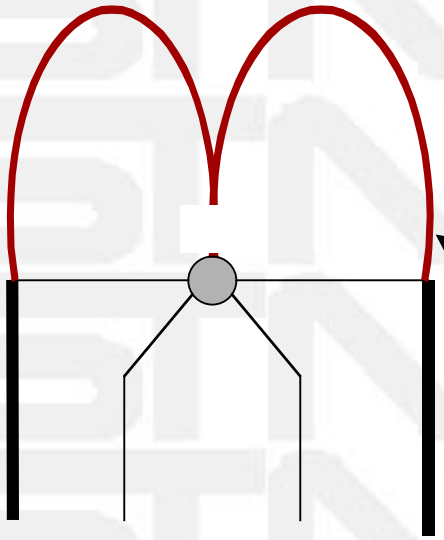


Voltage Measurements

Ac-dc Standards

- **MJTC Primary Standards**
  - Group of 10 MJTCs
  - Different construction
  - Different manufacturers } **Robustness!**
  - Different eras
  - Used for both voltage and current
  - Used from 2 V to 10 V, 2.5 mA to 25 mA, 40 Hz to 10 kHz
  - Intercompare to < 0.4 μV/V
  - Primary standard uncertainty: 0.5 μV/V

Temperature Gradients

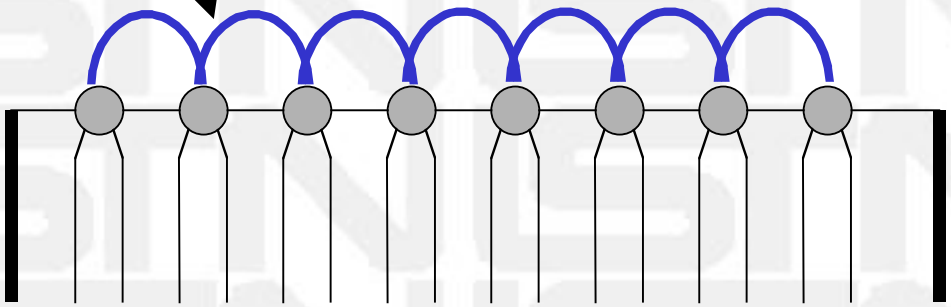


Single-junction thermal converter
Working temperature:
≈ 200 ºC above ambient

Large thermal gradients

Multijunction thermal converter
Working temperature:
≈ 50 ºC above ambient

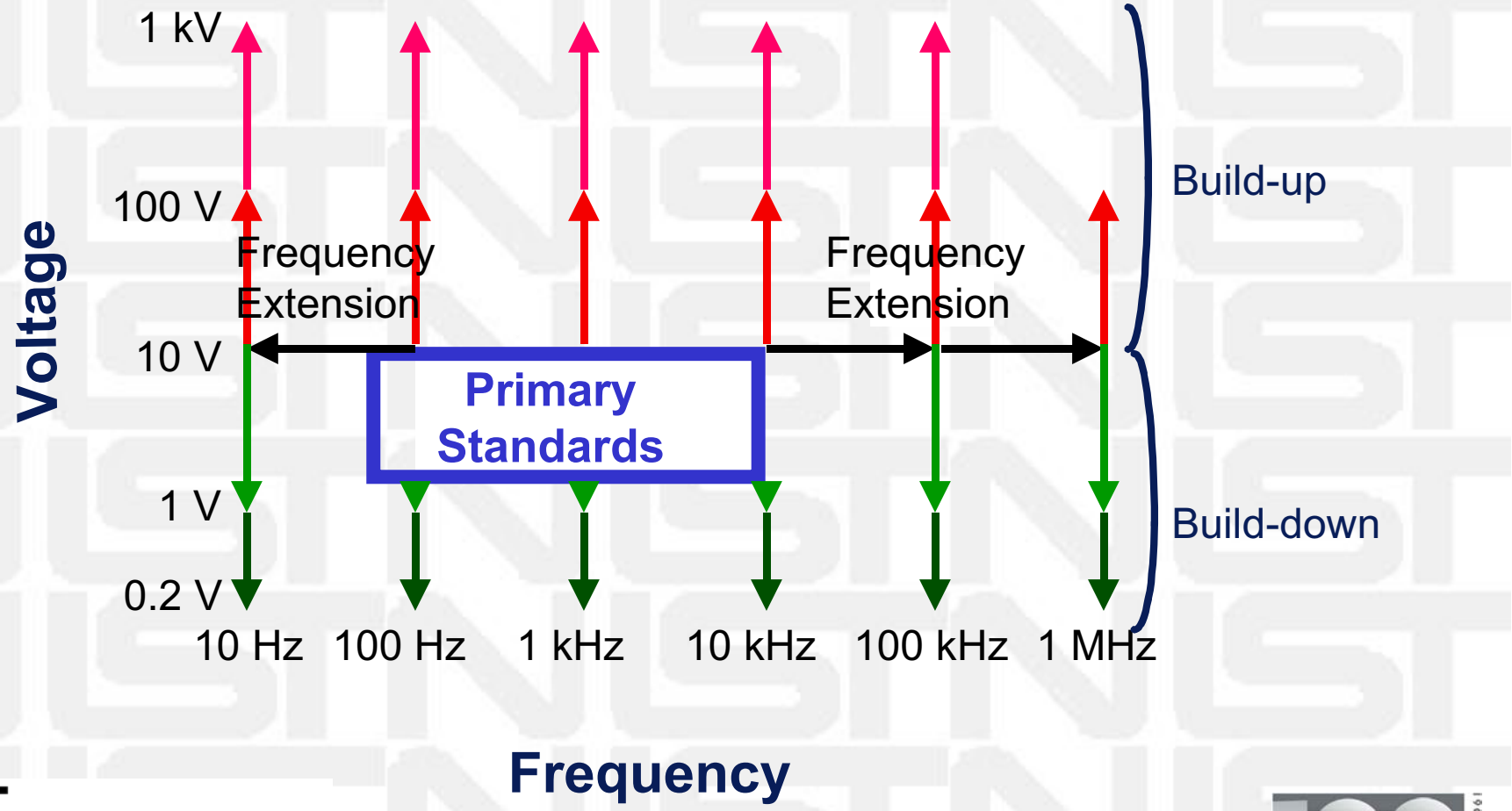
Small thermal gradients



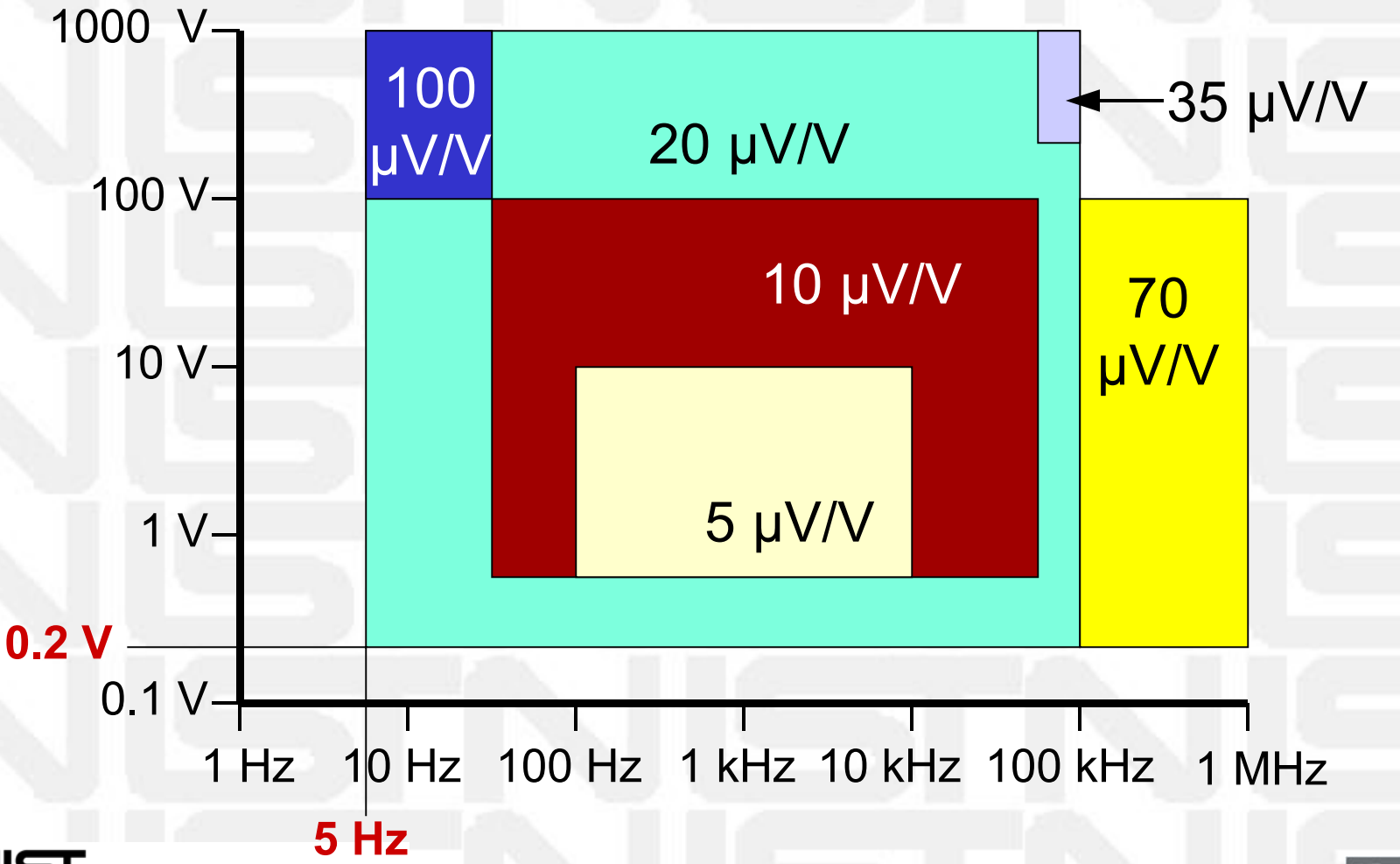
Ac-dc Standards

- **Voltage Converters**
  - Reference standards
    - Coaxial thermal converters
    - Special converters for frequency extensions
  - Working standards
    - Coaxial thermal converters
- **Current Converters**
  - Reference standards
    - High-current thermoelements
  - Working Standards
    - High current thermoelements
    - High current shunts

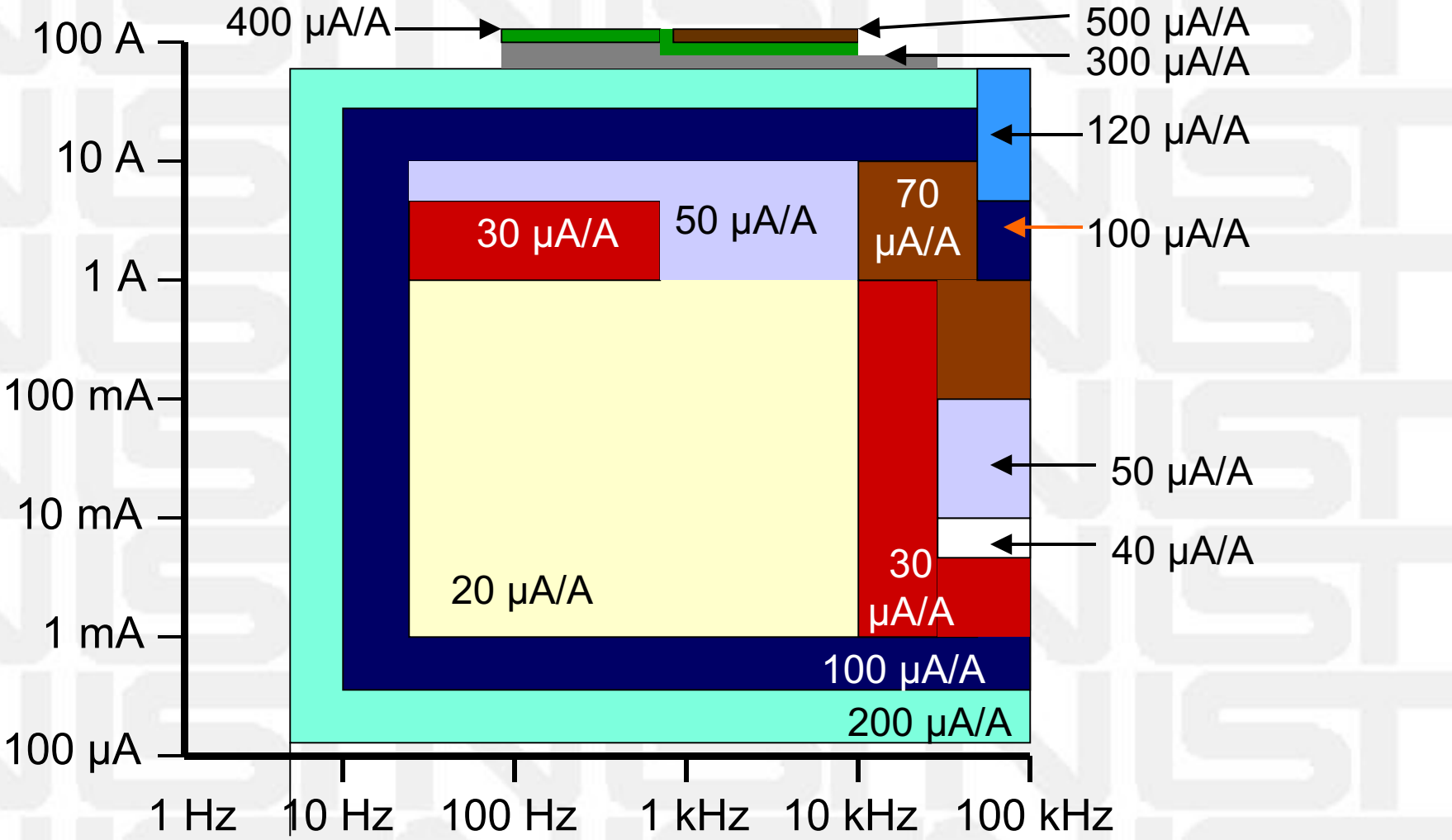
Voltage Build-up and Build-down



Parameter Space - Voltage*



Parameter Space - Current



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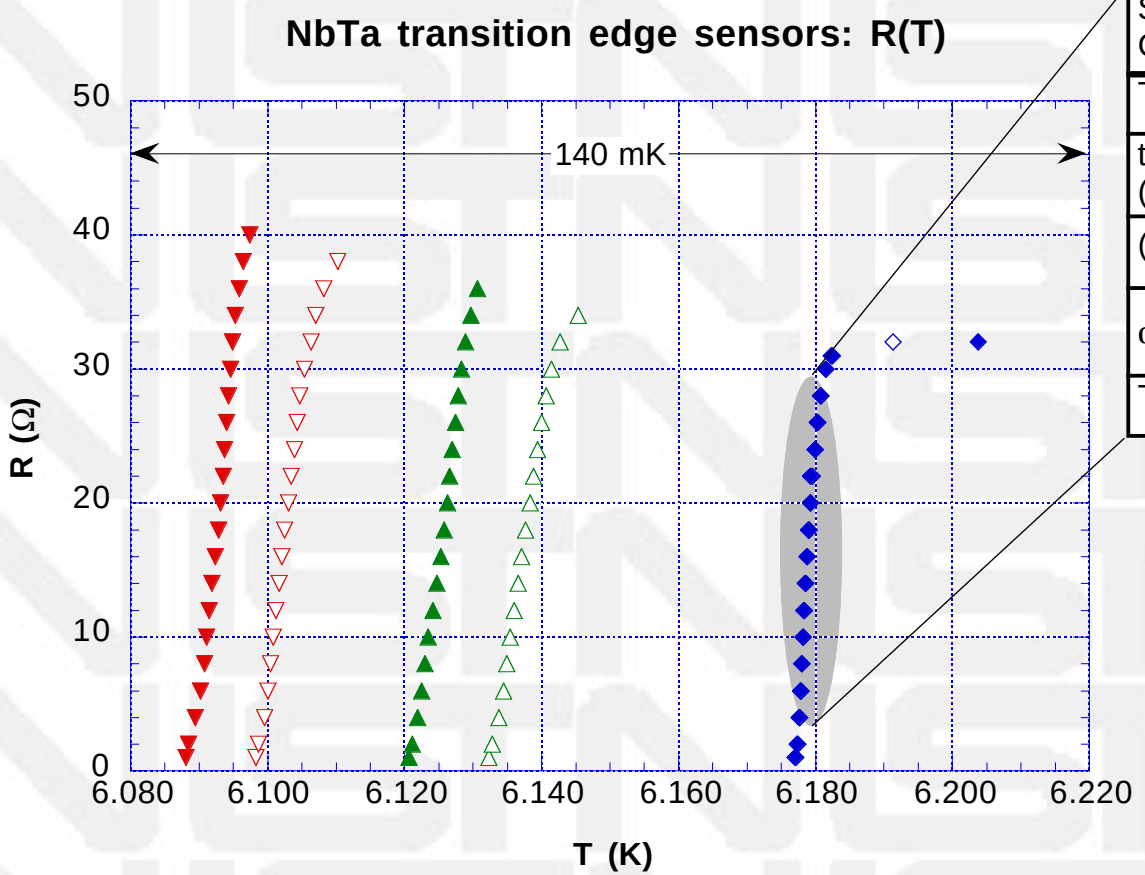
Research Activities - Cryogenic Thermal Transfer Standard (CTTS)

- **Goal: Develop new primary standard using cryogenic technology to**
  - Increase sensitivity
  - Reduce thermoelectric errors
  - Use at extremely low power levels to measure mV and μA

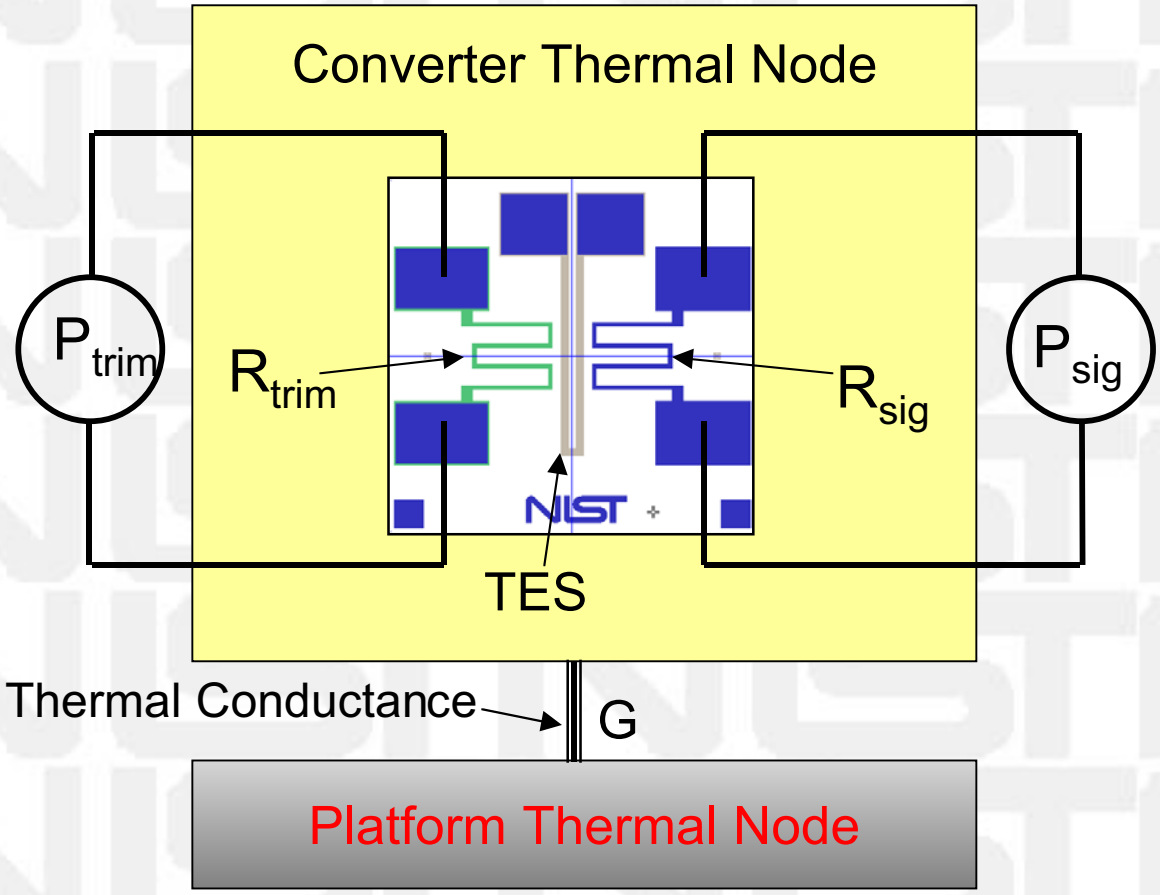
Transition-Edge Sensor



Sensor Characteristics	TES
T_c (K)	6.179
transition width (10-90%, mK)	3.1
$(dR/dT)_{peak}$ (Ω/K)	8000
$\alpha=1/R*(dR/dT)_{peak}$ (K^{-1})	500
$T/R*(dR/dT)_{peak}$	3090

Sensor Characteristic	thermocouple
$T-T_{ambient}$ (C)	150-200
$(dV/dT)_{peak}$ (μV/K)	100
$1/V*(dV/dT)_{peak}$ (K^{-1})	0.01
$T/V*(dV/dT)_{peak}$	<1

CTTS - Theory of Operation



$$P_{total} = P_{trim} + P_{sig}$$

$$P_{total} = G(T_c - T_{plat})$$

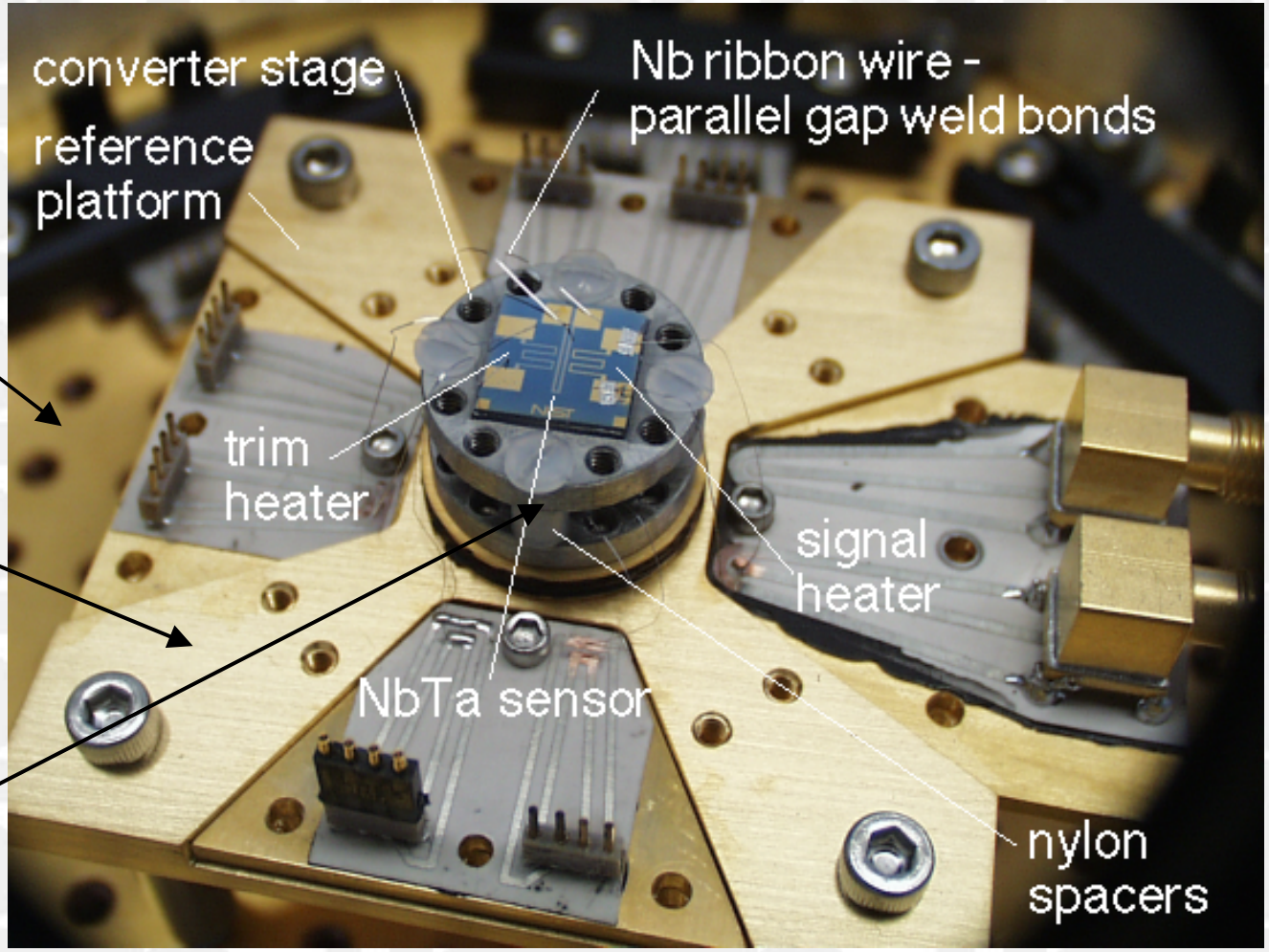
$$\Delta P_{trim} = -\Delta P_{sig}$$

CTTS - Experimental Platform

Cryostat Baseplate
4 K

Reference Platform
≈ 6 K

Thermal Converter Stage
6 K + ΔT_c

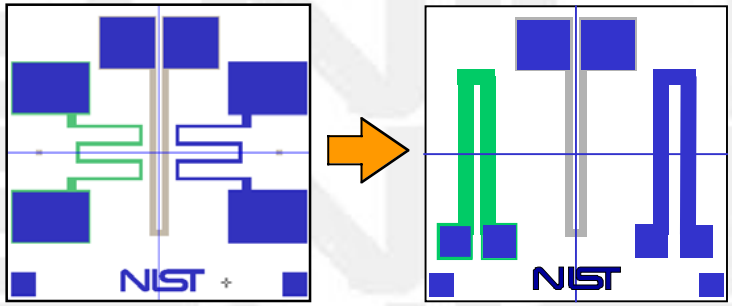


CTTS - Present Status

- Voltage converter measurements indicate large ac-dc differences at all frequencies
- Level coefficient measurements indicate decreasing ac-dc differences with decreasing input level
- Thermoelectric errors are negligble
- Conclusions
  - High frequency errors caused by transmission line
  - Audio-frequency errors caused by magnetic field coupling from heater into sensor

CTTS - Future Plans

- **Redesign sensor chip**
  - Bifilar heater arrangement
  - On-chip shielding

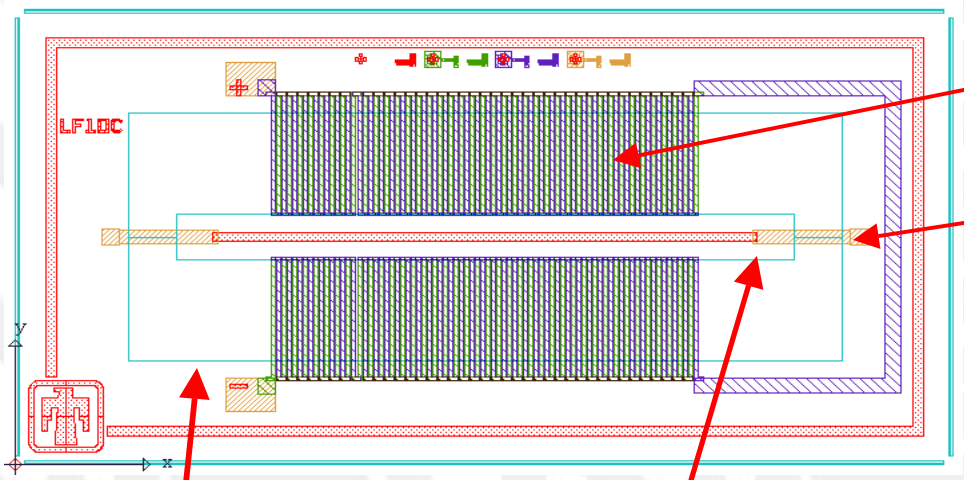


- **Redesign experimental platform**
  - Integrate platform and transmission line platform
  - Integrate sensor chip and transmission line
- **Improve resistance measurements**
- **Improve PID control**

Research Activities - Thin-Film Multijunction Thermal Converters (FMJTCs)

- **Goal:Use semiconductor fabrication technology to**
  - Fabricate new reference and working standards
  - Fabricate new thermal current converters

FMJTC - Design

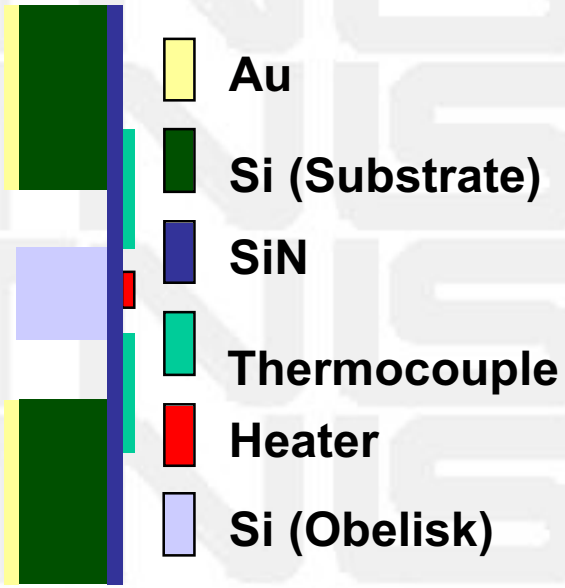


Thermocouples

Heater

Membrane Boundary

Silicon Obelisk



Au

Si (Substrate)

SiN

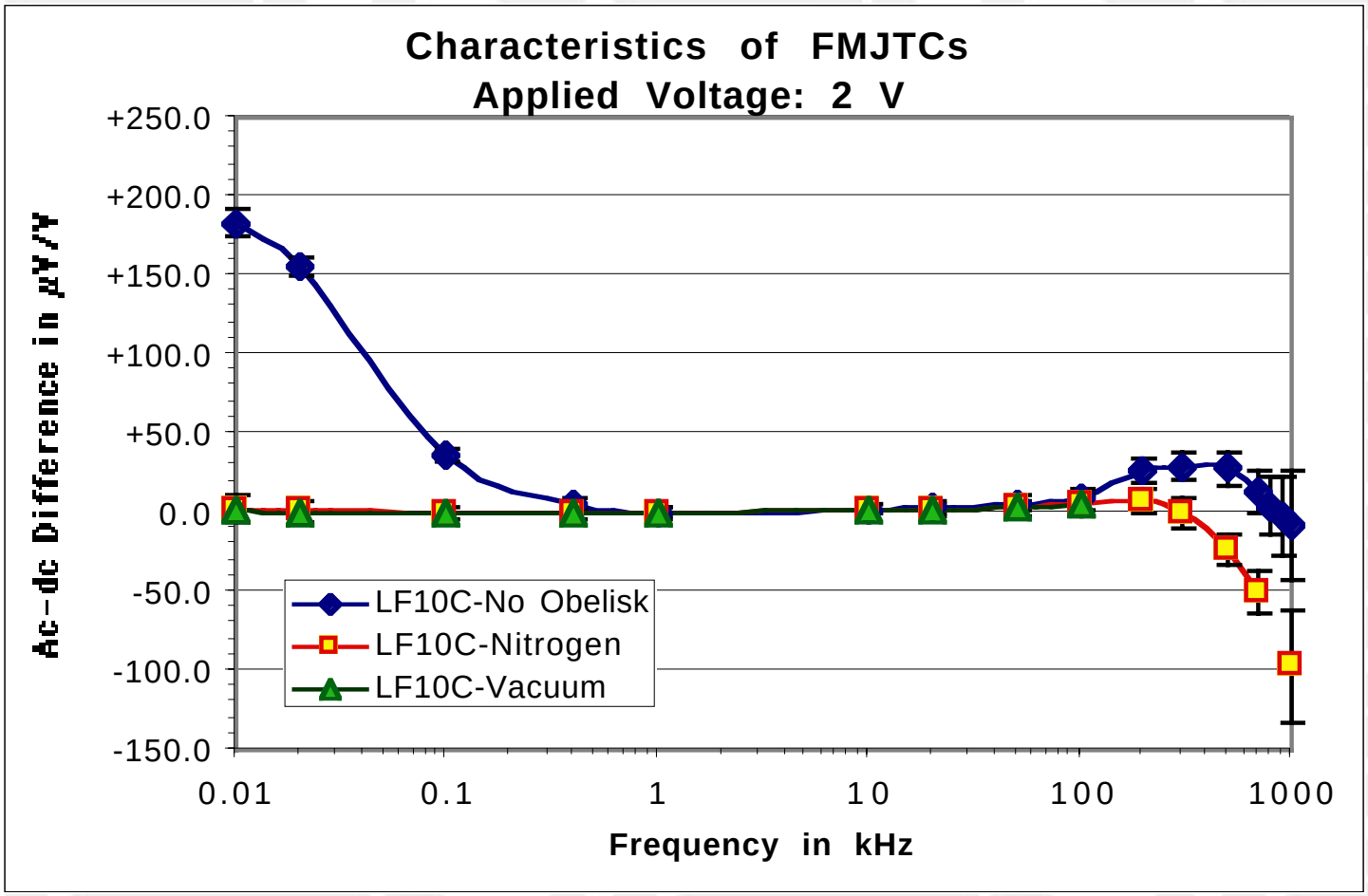
Thermocouple

Heater

Si (Obelisk)

Cross section of chip

FMJTC - Results



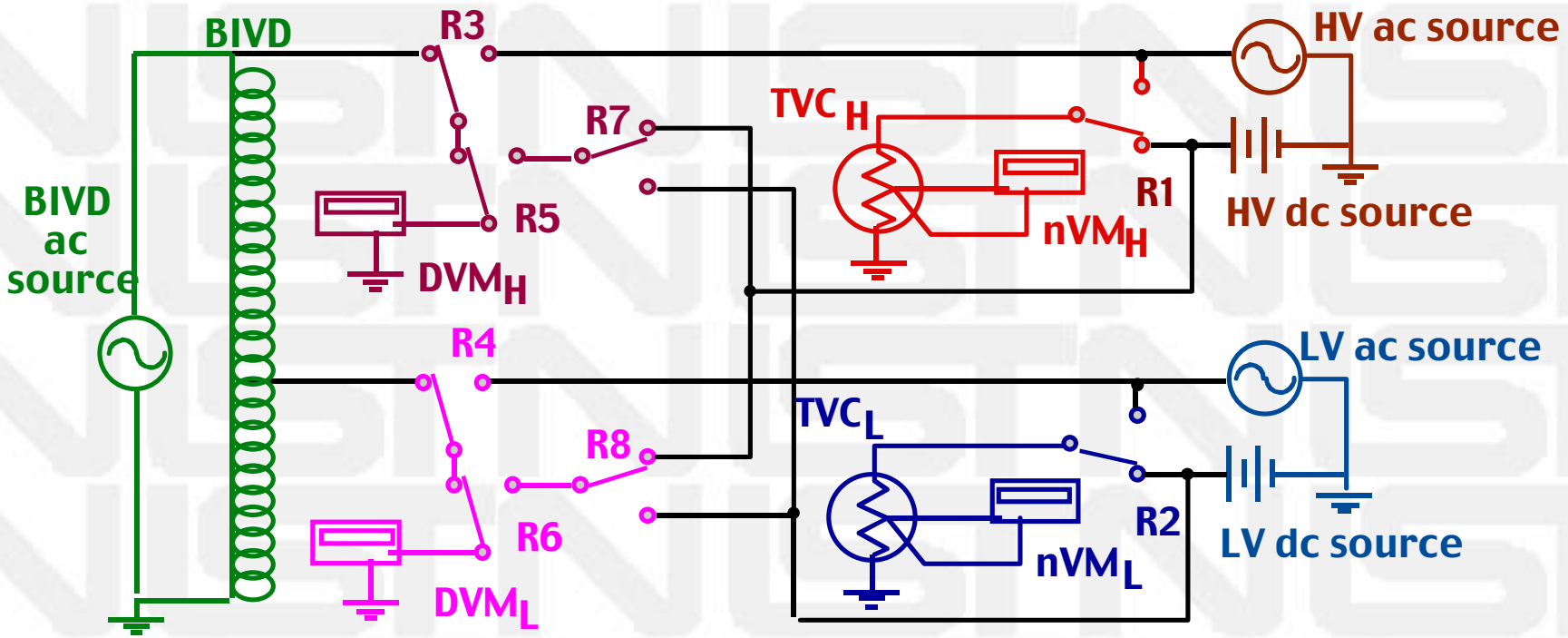
FMJTC - Future Plans

- **Fabricate high-current thermal converters**
  - Current levels to 1 A on a single chip
  - Multiple-converter module for currents to 20 A
  - Monitor vacuum-sealed converters for leaks

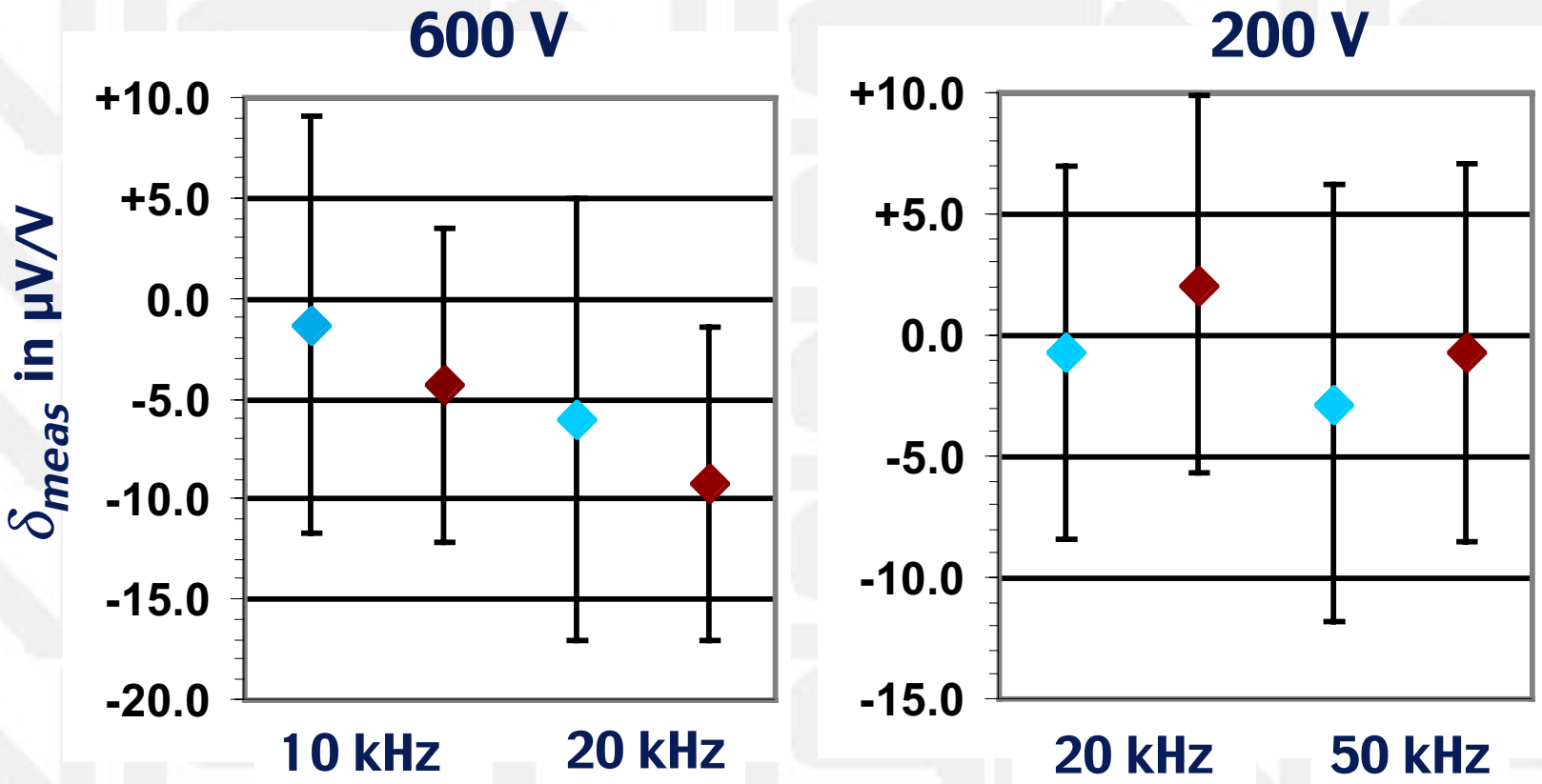
Research Activities - Binary Inductive Voltage Divider System

- **Construct measurement system based on a binary inductive voltage divider (BIVD) to**
  - Check accuracy and reproducibility of voltage build-up process
  - Improve thermal converter measurements at voltages up to 1000 V

BIVD - Schematic



BIVD - Results



- Results from build-up
- Results from BIVD

BIVD - Future Plans

- Increase voltage/frequency ranges to 1000 V at 20 kHz
- Check Build-up methodology to 1000 V
- Reduce Type A errors of BIVD system
- Use in CCEM-K9 (international intercomparison of high-voltage thermal converters)